# Validation of EarthCARE Aerosol Products Using Ground-Based Lidar and UAV Observations in Cyprus and Greece


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ATMO ACCESS
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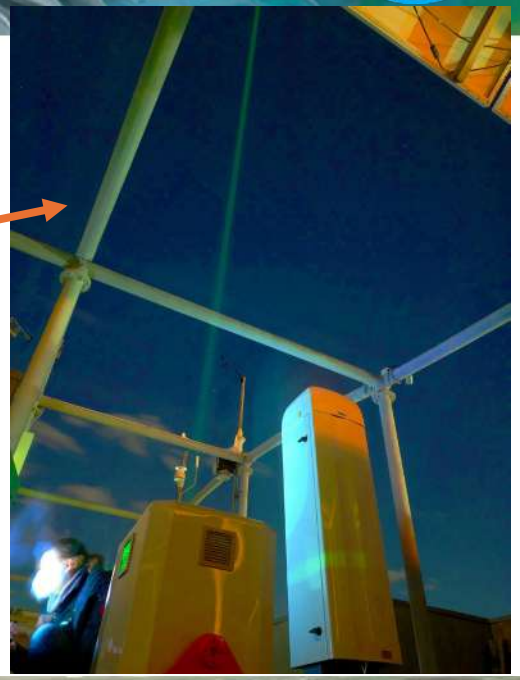
2nd ESA-JAXA EarthCARE In-Orbit Validation Workshop
17 – 20 March 2025 | ESA-ESRIN | Frascati (Rome), Italy

# The sites in Cyprus



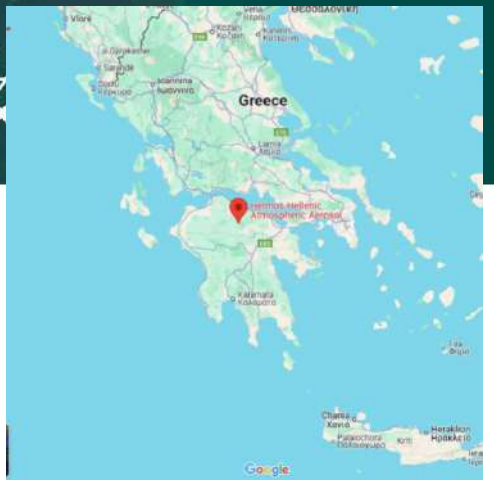




# Mt. Helmos, Greece

HELIKITE

HEMBA~1750 m a.s.l





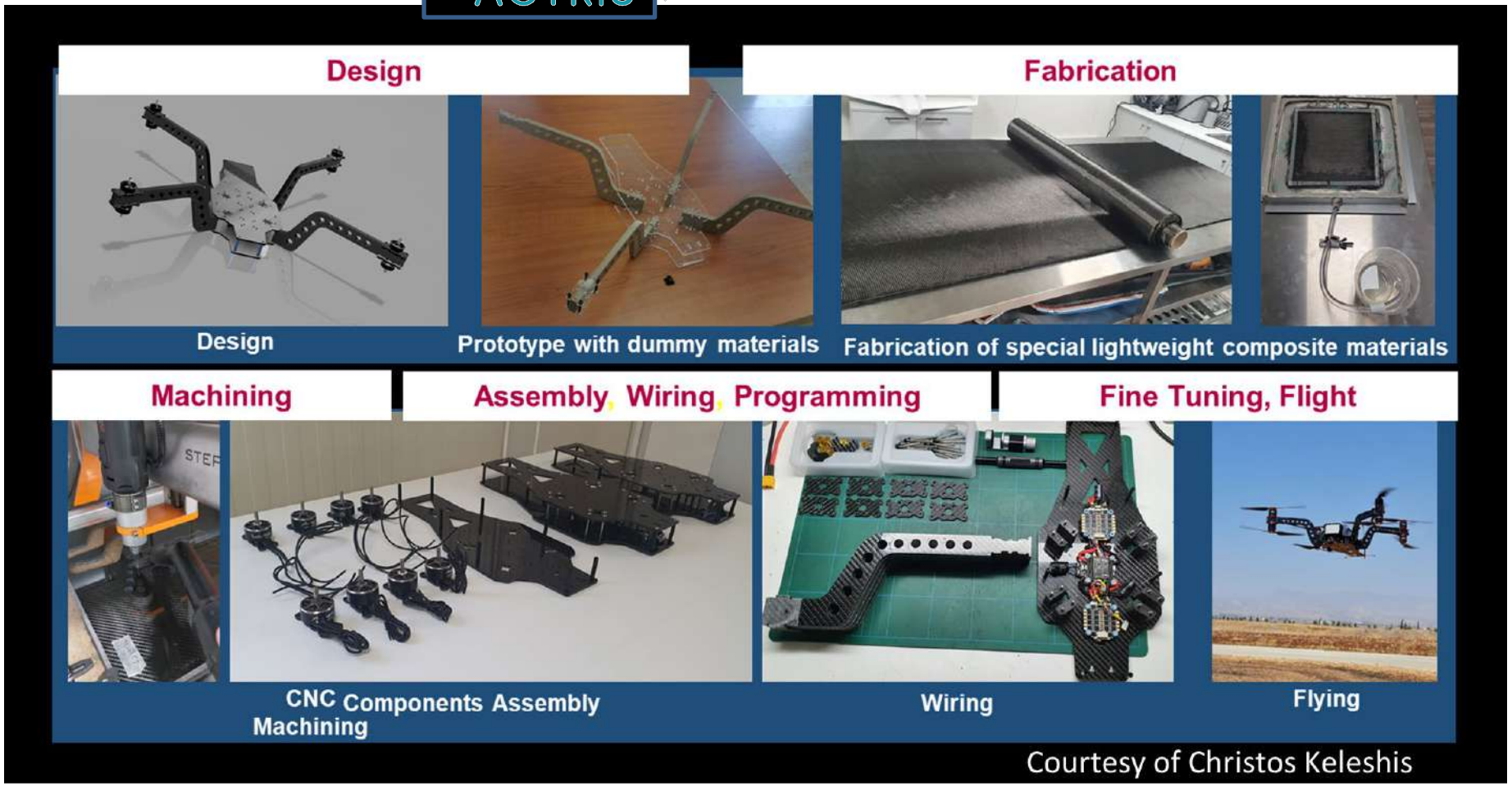

(HAC)2~2340m a.s.l

Parking lot~1690m a.s.l

# Cyprus Atmospheric Observatory: Remote Sensing

- A network of ground-based instruments at three **Cyprus Atmospheric Observatory** stations : *sunphotometers, ceilometers, 1 lidar and 1 flux station*.


# Unmanned Systems Research Laboratory (USRL)


# UAV sensors for dust and other aerosols

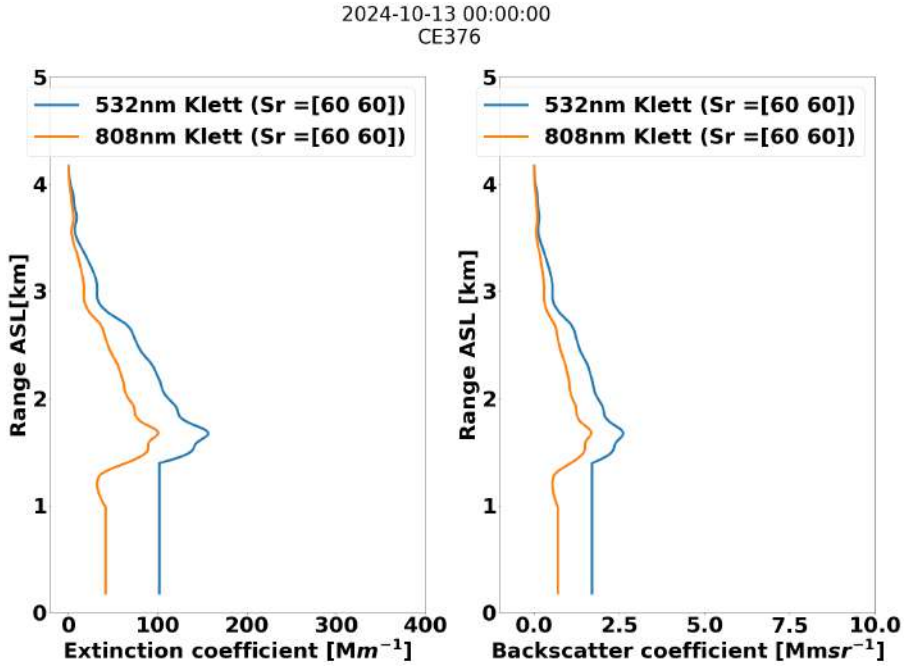

| SENSOR | UCASS  | GPAC  | COBALD  | POPS  |
|---|---|---|---|---|
| USE | Aerosol size distribution 0.4–20 // 3–40 µm | Impactors (>1µm ) | Backscatter ratio (2 orientations) | Aerosol size distribution 0.14–3.3 µm |

# CAO Nicosia-Cyl

| Date | | EarthCARE Overpass | | Distanse (km) | Lidar Data | | AOD 440 (Aeronet) | Clear/Cloudy |
|---|---|---|---|---|---|---|---|---|
| | | Start UTC time | End UTC time | | Start (UTC) | End (UTC) | Daily Average | During Overpass |
| 02/07/2024 | Monday | 12:09:38 | 12:10:06 | | 11:00:00 | 13:00:00 | 0.147 | Clear sky |
| 25/07/2024 | Friday | 22:00:00 | 0:00:00 | 48.611115 | 22:00:00 | 0:00:00 | 0.428 | Clear sky |
| 28/07/2024 | Monday | 11:00:00 | 13:00:00 | 5.364709 | 11:00:00 | 13:00:00 | 0.119 | Clear sky |
| 08/08/2024 | Thursday | 11:00:00 | 13:00:00 | -37.669237 | 11:00:00 | 13:00:00 | 0.264 | Clear sky |
| 14/08/2024 | Wednesday | 22:00:00 | 0:00:00 | -61.737883 | 22:00:00 | 0:00:00 | 0.159 | Clear sky |
| 17/08/2024 | Saturday | 11:00:00 | 13:00:00 | 56.622297 | 11:00:00 | 13:00:00 | 0.141 | Clear sky |
| 23/08/2024 | Friday | 22:00:00 | 0:00:00 | -56.893179 | 22:00:00 | 0:00:00 | 0.394 | Clear sky |
| 26/08/2024 | Monday | 11:00:00 | 13:00:00 | 19.0837 | 11:00:00 | 13:00:00 | 0.304 | Cloudy |
| 01/09/2024 | Sunday | 22:00:00 | 0:00:00 | 33.294286 | 22:00:00 | 0:00:00 | 0.161 | Clear sky |
| 04/09/2024 | Wednesday | 11:00:00 | 13:00:00 | -85.388822 | 11:00:00 | 13:00:00 | 0.274 | Cloudy |
| 11/09/2024 | Wednesday | 11:00:00 | 13:00:00 | 62.998981 | 11:00:00 | 13:00:00 | 0.165 | Clear sky |
| 17/09/2024 | Tuesday | 22:00:00 | 0:00:00 | -21.639679 | 22:00:00 | 0:00:00 | 0.07 | Clear sky |
| 19/09/2024 | Thursday | 22:00:00 | 0:00:00 | | 22:00:00 | 0:00:00 | 0.1 | Clear sky |
| 20/09/2024 | Friday | 11:00:00 | 13:00:00 | -27.383745 | 11:00:00 | 13:00:00 | 0.122 | Cloudy |
| 26/09/2024 | Thursday | 22:00:00 | 0:00:00 | 66.781317 | 22:00:00 | 0:00:00 | 0.098 | Clear sky |
| 29/09/2024 | Sunday | 11:00:00 | 13:00:00 | 30.20166 | 11:00:00 | 13:00:00 | 0.099 | Clear sky |
| 05/10/2024 | Saturday | 22:00:00 | 0:00:00 | 67.09159 | 22:00:00 | 0:00:00 | 0.081 | Clear sky |
| 12/10/2024 | Saturday | 22:00:00 | 0:00:00 | 98.25164 | 22:00:00 | 0:00:00 | 0.221 | Clear sky |
| 15/10/2024 | Tuesday | 11:00:00 | 13:00:00 | 52.42295 | 11:00:00 | 13:00:00 | 0.219 | Clear sky |
| 21/10/2024 | Monday | 22:00:00 | 0:00:00 | 15.50546 | 22:00:00 | 0:00:00 | 0.068 | Clear sky |
| 24/10/2024 | Thursday | 11:00:00 | 13:00:00 | 30.20165 | 11:00:00 | 13:00:00 | 0.074 | Clear sky |
| 30/10/2024 | Wednesday | 22:00:00 | 0:00:00 | 67.09159 | 22:00:00 | 0:00:00 | 0.19 | Clear sky |
| 06/11/2024 | Wednesday | 22:00:00 | 0:00:00 | 98.25149 | 22:00:00 | 0:00:00 | 0.122 | Clear sky |
| 09/11/2024 | Saturday | 11:00:00 | 13:00:00 | 52.4231 | 11:00:00 | 13:00:00 | 0.181 | |
| 15/11/2024 | Friday | 22:00:00 | 0:00:00 | 15.79428 | 22:00:00 | 0:00:00 | 0.132 | Clear sky |
| 18/11/2024 | Monday | 11:00:00 | 13:00:00 | 30.49042 | 11:00:00 | 13:00:00 | 0.049 | Cloudy |
| 24/11/2024 | Sunday | 22:00:00 | 0:00:00 | 66.80168 | 22:00:00 | 0:00:00 | - | Clear sky |
| 01/12/2024 | Sunday | 22:00:00 | 0:00:00 | -98.463314 | 22:00:00 | 0:00:00 | 0.192 | Clear sky |
| 04/12/2024 | Wednesday | 11:00:00 | 13:00:00 | 52.08085 | 11:00:00 | 13:00:00 | 0.167 | Cloudy |
| 10/12/2024 | Tuesday | 22:00:00 | 0:00:00 | -15.716537 | 22:00:00 | 0:00:00 | - | Cloudy |
| 13/12/2024 | Friday | 11:00:00 | 13:00:00 | -30.541841 | 11:00:00 | 13:00:00 | 0.117 | Clear sky |
| 19/12/2024 | Thursday | 22:00:00 | 0:00:00 | 66.878438 | 22:00:00 | 0:00:00 | 0.271 | Cloudy |
| 26/12/2024 | Thursday | 22:00:00 | 0:00:00 | 21.485598 | 22:00:00 | 0:00:00 | 0.137 | Clear sky ?? |
| 29/12/2024 | Sunday | 11:00:00 | 13:00:00 | 52.133204 | 11:00:00 | 13:00:00 | - | Cloudy ?? |
| 04/01/2025 | Saturday | 22:00:00 | 0:00:00 | 15.794205 | 22:00:00 | 0:00:00 | 0.287 | Cloudy |
| 07/01/2025 | Tuesday | 11:00:00 | 13:00:00 | 30.490323 | 11:00:00 | 13:00:00 | 0.242 | Clear sky |
| 13/01/2025 | Monday | 22:00:00 | 0:00:00 | 66.801758 | 22:00:00 | 0:00:00 | - | Clear sky? |
| 20/01/2025 | Monday | 22:00:00 | 0:00:00 | 98.539374 | 22:00:00 | 0:00:00 | 0.063 | Clear sky |
| 23/01/2025 | Thursday | 11:00:00 | 13:00:00 | 52.133204 | 11:00:00 | 13:00:00 | - | Cloudy |
| 29/01/2025 | Wednesday | 22:00:00 | 0:00:00 | 15.794205 | 22:00:00 | 0:00:00 | 0.209 | Clear sky |
| 01/02/2025 | Saturday | 11:00:00 | 13:00:00 | | 11:00:00 | 13:00:00 | 0.143 | Clear sky |
| 07/02/2025 | Friday | 22:00:00 | 0:00:00 | | 22:00:00 | 0:00:00 | - | Clear sky |
| 14/02/2025 | Friday | 22:00:00 | 0:00:00 | 98.69322 | 22:00:00 | 0:00:00 | - | Clear sky |
| 17/02/2025 | Monday | 11:00:00 | 13:00:00 | 51.97837 | 11:00:00 | 13:00:00 | - | Cloudy |

CAO-Cyl Nicosia Overpasses **532 nm**

- **44 lidar profiles** submitted in EVDC (July 2024 – February 2025)
- **20** daytime profiles and **24** nighttime.
- **31** profiles with clear sky conditions
- Extinction coefficient @532
- Volume depolarization ratio @532



# UAV Orounda and Helmos

| Overpass Timestamp | Sensor | Flight location | Distance to mid swath (km) | Version (POPS/UCASS) |
|---|---|---|---|---|
| 2024-09-27T12:16:49.811356 | UCASS & POPS | Orounda | 194.8794 | v2/v1 |
| 2024-10-14T12:59:47.409143 | POPS | Helmos | 139.9733 | v2/ |
| 2024-10-16T12:48:18.619940 | UCASS&POPS | Helmos | 107 | v2/v2 |
| 2024-10-25T12:44:51.326743 | POPS | Helmos | 183 | |
| 2024-11-01T12:51:45.324149 | POPS&UCASS | Helmos | 24.47496 | v1/v2 |
| 2024-11-25T12:12:16.197366 | POPS | Orounda | 123.33 | v2/ |
| 2024-12-04T12:07:20.125043 | POPS&UCASS | Orounda | 18.356014 | v2/v1 |
| 2024-12-13T12:03:50.228929 | POPS | Orounda | 56.26793 | v2/ |
| 2025-01-14T12:10:36.291175 | POPS&UCASS | Orounda | 109 | v2/v1 |
| 2025-01-23T12:06:49.181911 | POPS | Orounda | 26 | v2/ |
| 2025-02-01T12:03:00.582339 | POPS&UCASS | Orounda | 56 | v2/v1 |
| 2025-02-08T12:10:15.936332 | POPS&UCASS | Orounda | 107 | v2/v1 |
| 2025-02-26T12:02:33.832640 | POPS&UCASS | Orounda | 56 | v2/v1 |

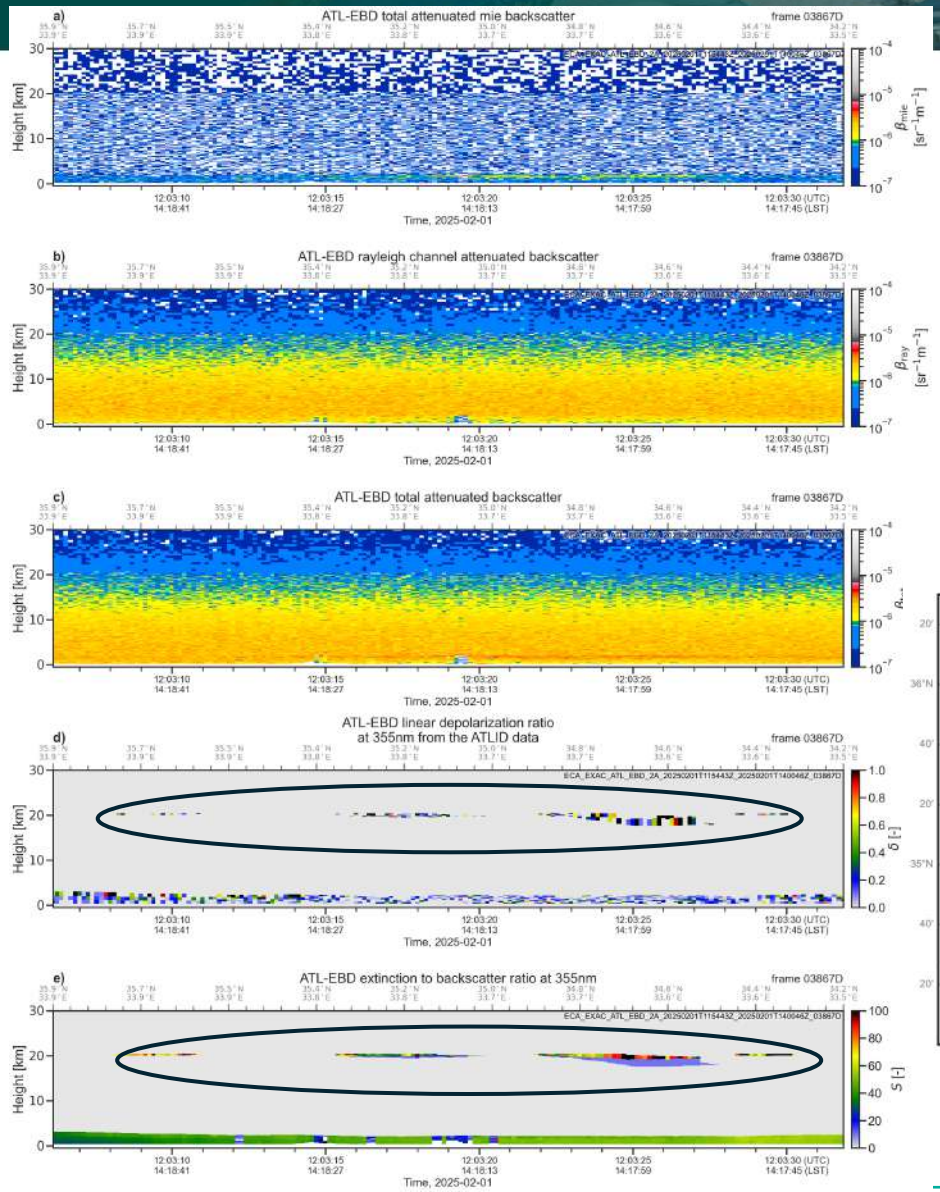
USRL Orounda and Helmos UAV profiles

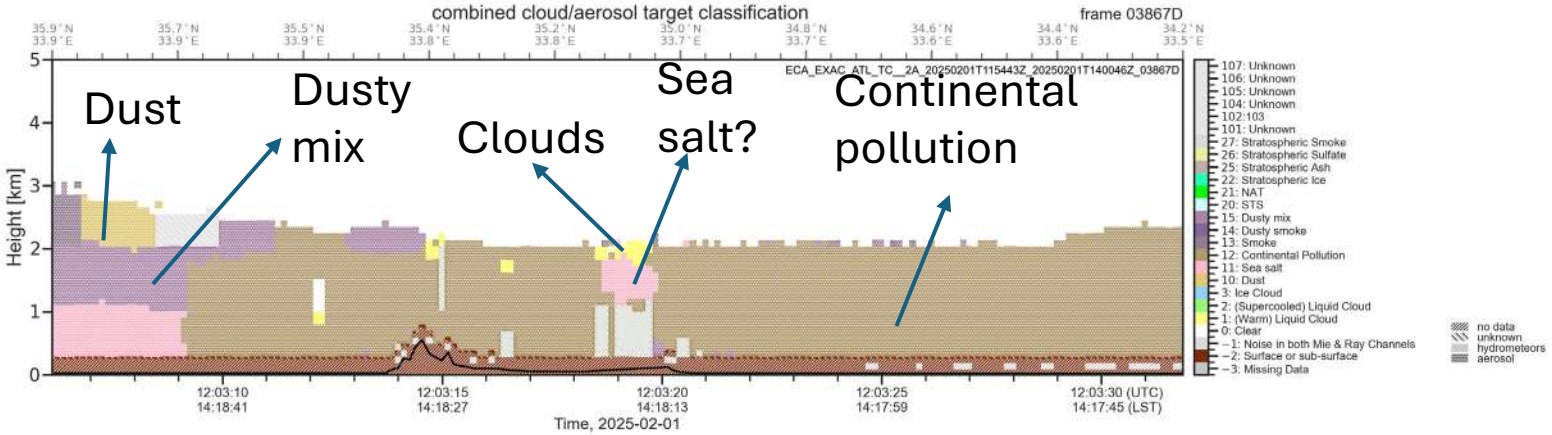
- **13 profiles** submitted in EVDC (September 2024 – February 2025)
- **9 overpasses** over Orounda and **4** over Helmos during the CleanCloud campaign
- **5 flights** only with **POPS**, 8 combined **POPS** and **UCASS**
- **4 profiles** coincident with **Lidar/Nicosia** measurements

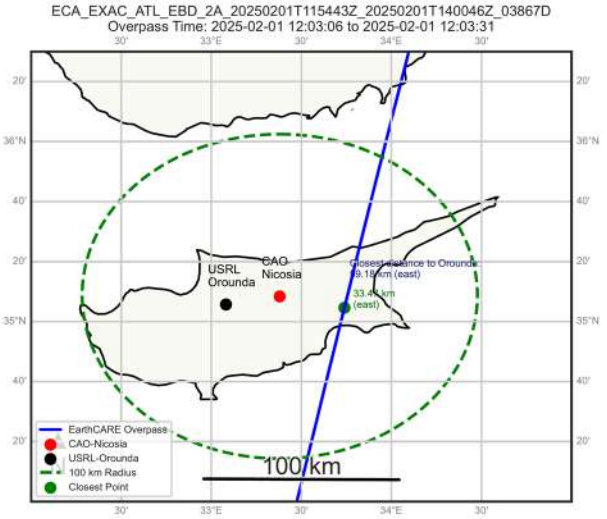
# Methodology

- **Data Acquisition**: ATL-EBD and ATL-TC EarthCARE products corresponding to the predicted overpass frames over Nicosia and Orounda were retrieved from ESA's Online Access Dissemination System (https://ec-pdgs-dissemination2.eo.esa.int/). **Baseline AC**
- **Spatial Selection**: EarthCARE products were extracted for overpasses occurring within 100 km of the Nicosia (Orounda) station. The distances between EarthCARE's latitude/longitude coordinates and the ground station were computed using the haversine formula.
- **Cloud Filtering**: Cloud-contaminated profiles were masked and excluded from further analysis to ensure a direct aerosol comparison. The simple classification scheme from the ATC product was used for masking the clouds.
- **Profile Averaging**: Mean vertical profiles of **Backscatter Coefficient**, **Extinction Coefficient**, **Lidar Ratio**, and **Particle Depolarization Ratio** were computed for the selected profiles (within 100 km) after cloud screening, enabling direct comparison with ground-based lidar and UAV measurements.

# 20250201 EBD and ATC EarthCARE products

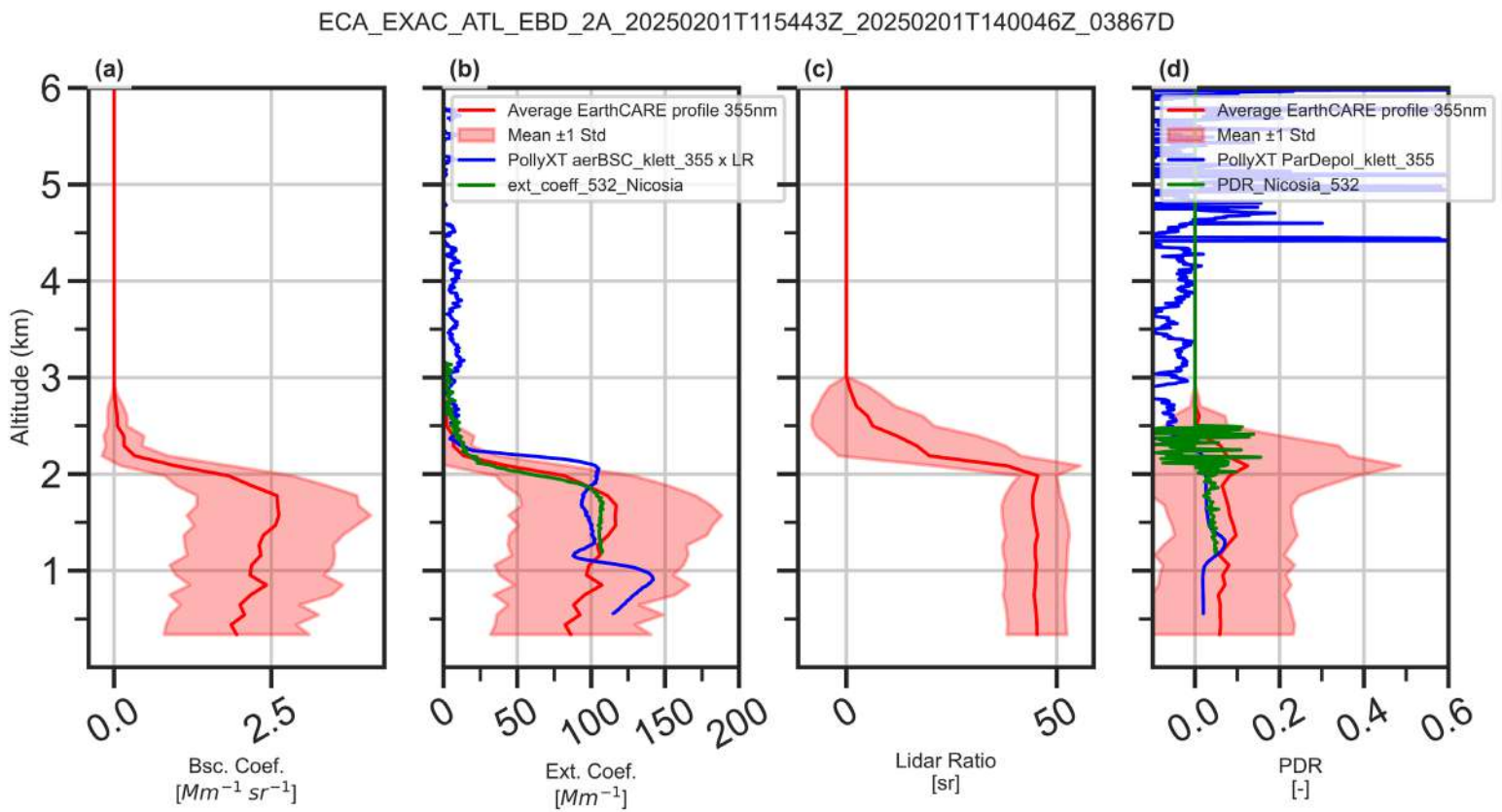



- **Closest overpass**: ~33 km east of Nicosia and ~59 km east of USRL Orounda.
- **Stratospheric aerosol layer (sulfate)**: Observed at ~20 km altitude, not detected from the ground.
- **Continental pollution**: the main aerosol type based on ATC classification, reaching up to ~2.2 km.
- **Sea salt and dust-dusty mix**: Classified by ATC over the sea to the northeast, extending up to 3 km.
- **Sea salt beneath clouds**: Possible artifact?

# 20250201 comparison with lidar measurements

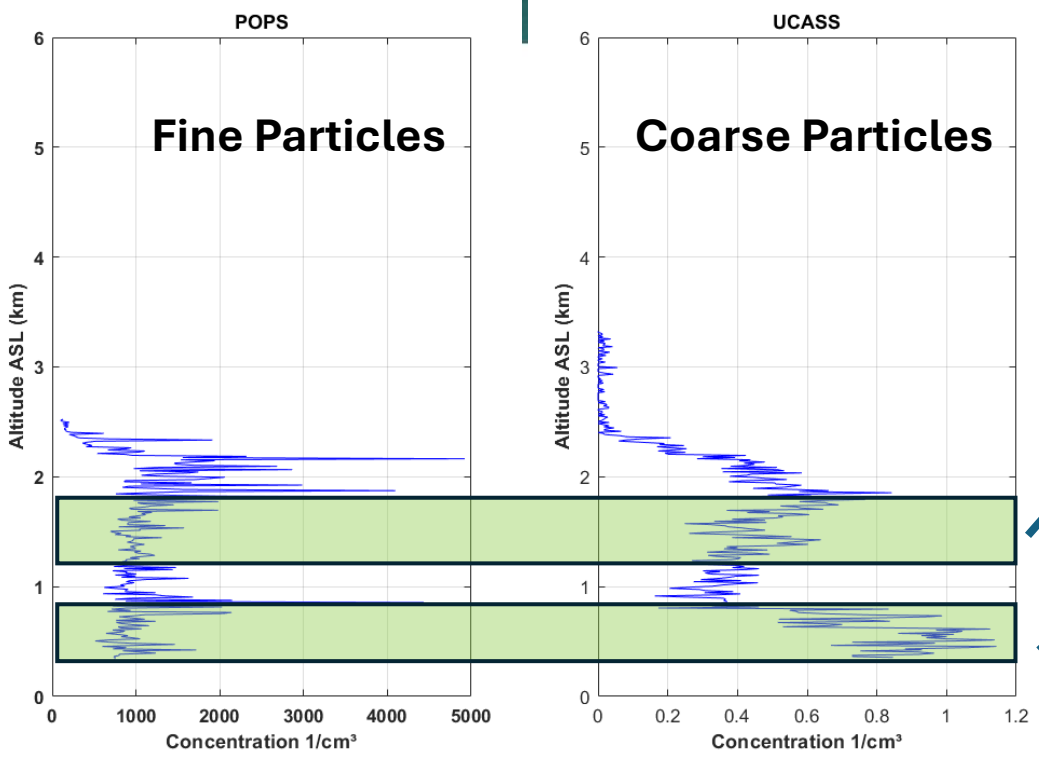


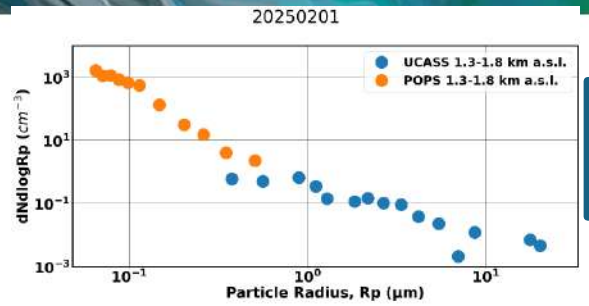

- EarthCARE overpass 12:03:07 – 12:03:31
- Nicosia lidar average 12:00 – 12:30 UTC **532 nm**
- PollyXT Limassol average 11:42 – 12:42 UTC

**baseline AC**

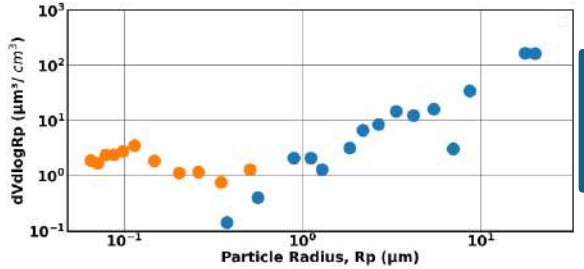
- **Nicosia Lidar**: extinction coefficient @532 nm remains ~100 $Mm^{-1}$ up to ~1.8 km, then decline reaching near-zero at ~2.4 km, low **PDR** (~3%) **532 nm**
- **PollyXt Limassol:** extinction coefficient @355 nm ~100 $Mm^{-1}$ up to ~2 km, reaching zero ~2.4 km, low **PDR** (~3%)
- **EarthCARE EBD**: extinction coefficient @355 nm remains ~100 $Mm^{-1}$ up to ~1.8 km, then decline reaching near-zero at ~2.4 km, low **PDR** (~6%)
- Both Nicosia and Limassol Lidar profiles are compatible with **continental pollution** in line with EarthCARE ATC classification

# 20250201 UAV observations

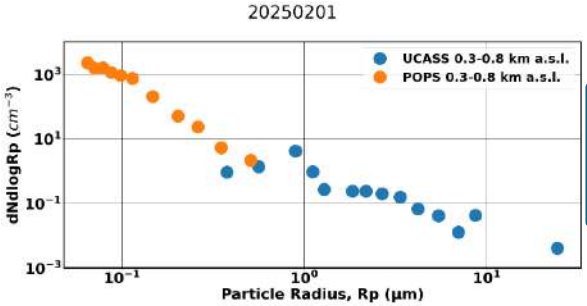


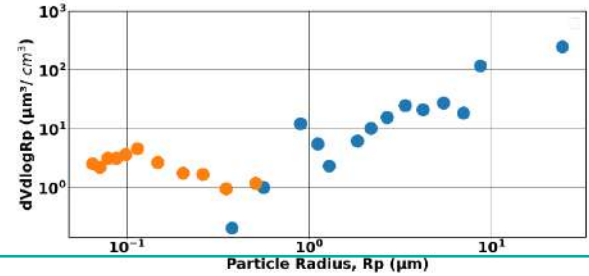

number size distribution




volume size distribution



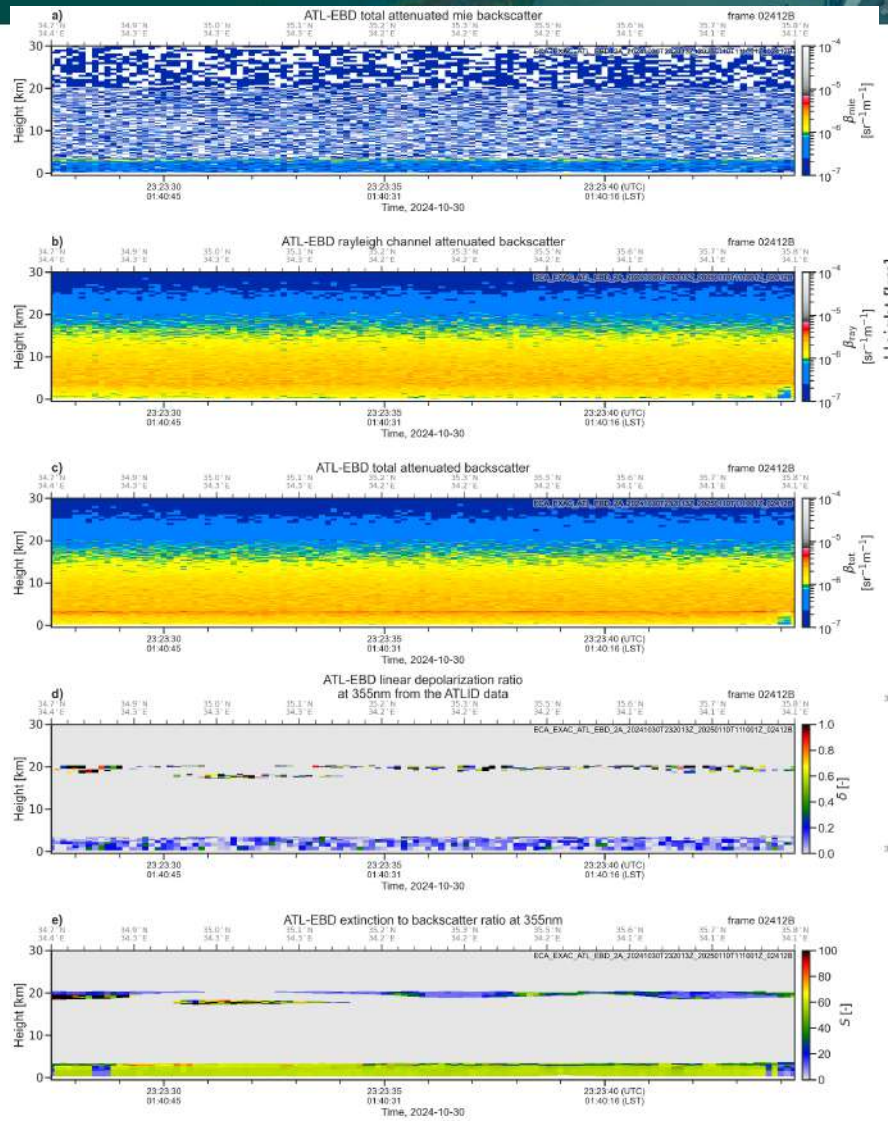

number size distribution

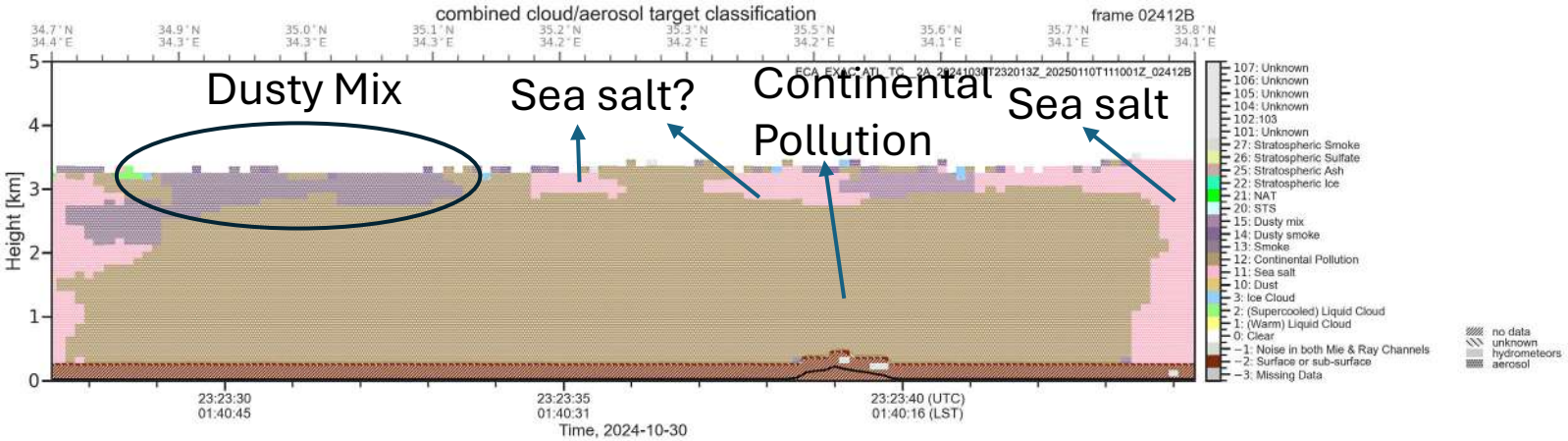


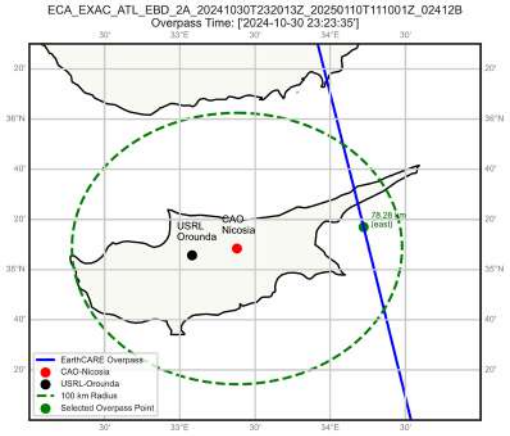

volume size distribution

- POPS concentrations >1000 particles/cm³, UCASS significantly lower concentrations ~1 particle/cm³
- POPS: well-mixed aerosol layer confined below ~2.2 km, similar with extinction coefficient observations from lidar and EarthCARE
- **number size distribution** indicates a dominance of fine-mode particles (<0.3 µm), **consistent** with EarthCARE ATC.

# 20241030 EBD and ATC EarthCARE products

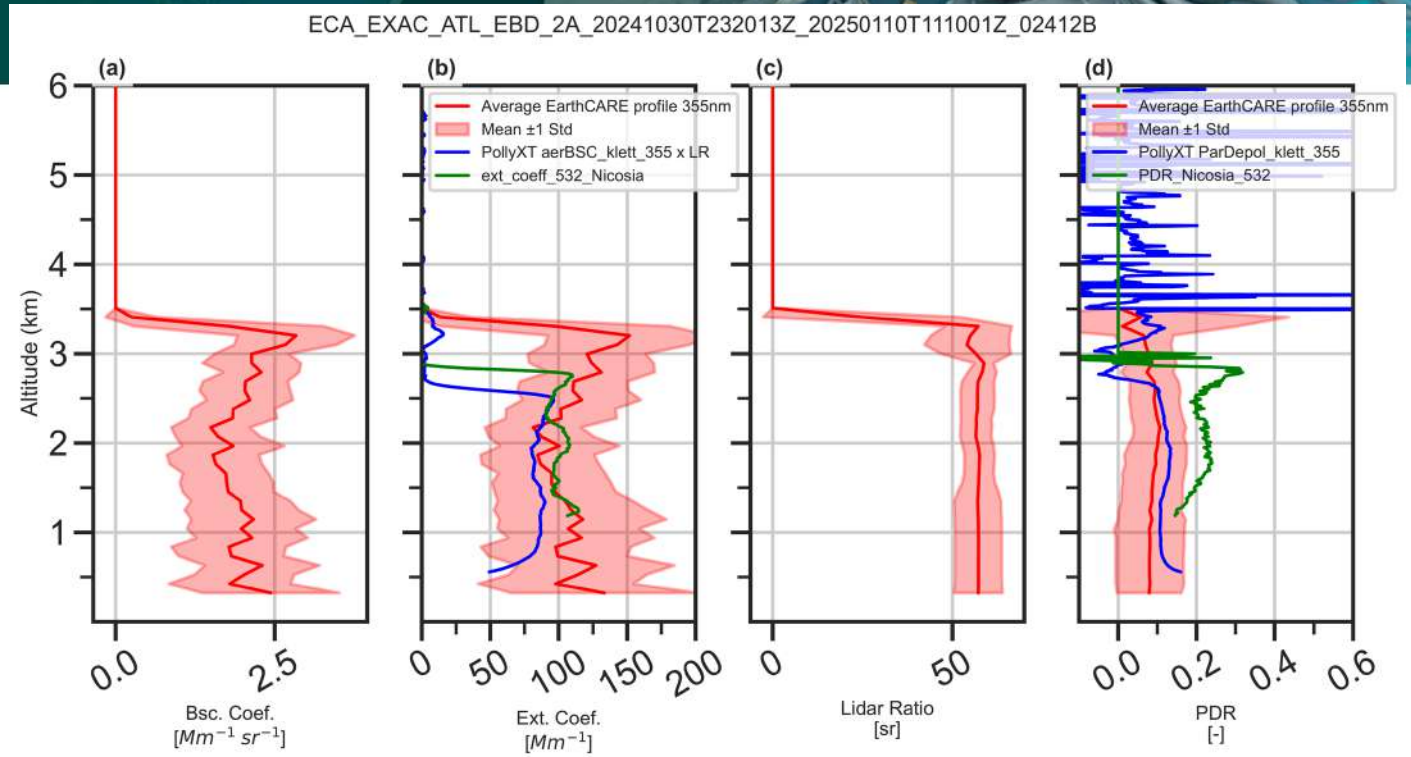



- **Closest overpass**: ~59 km east of Nicosia
- **Stratospheric aerosol layer (sulfate)**: at ~20 km altitude from ATC classification, not detected from the ground.
- **Continental pollution**: The dominant aerosol type.
- **Dusty mix:** Over the sea to the southeast, extending from ~2.5 to ~3.3 km, according to ATC classification.
- **Sea salt** : Classified by ATC in the northeast and in some layers above continental pollution, between ~2.7 and ~3.2 km.

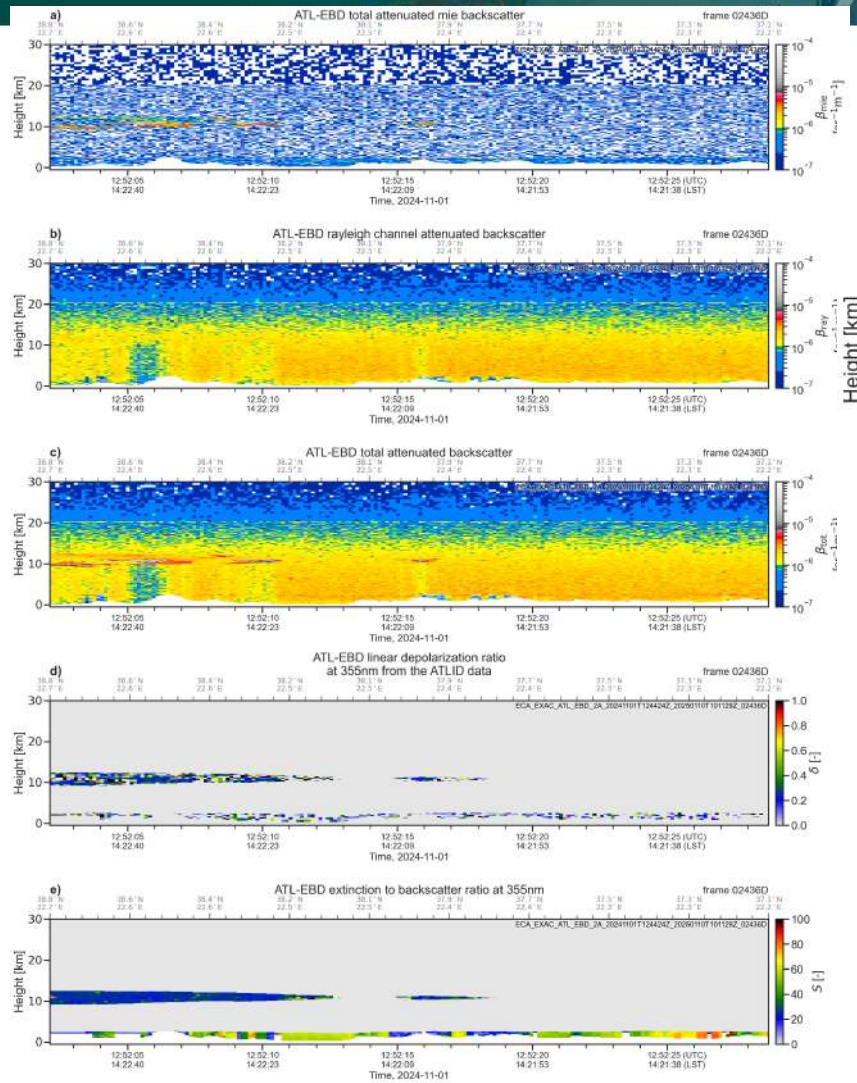
# 20241030 comparison with lidar measurements

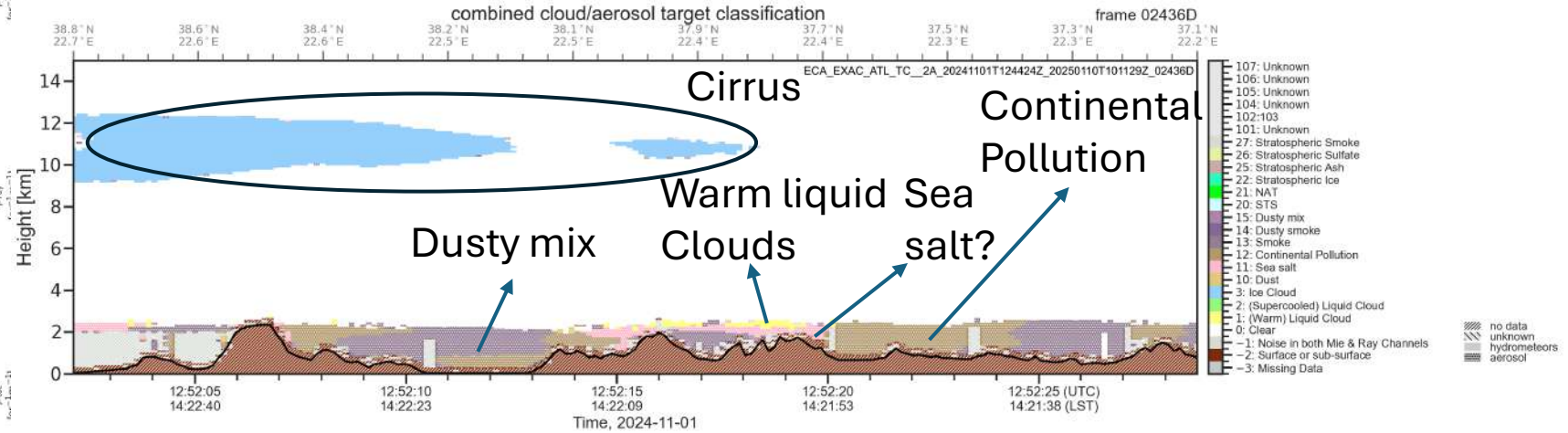


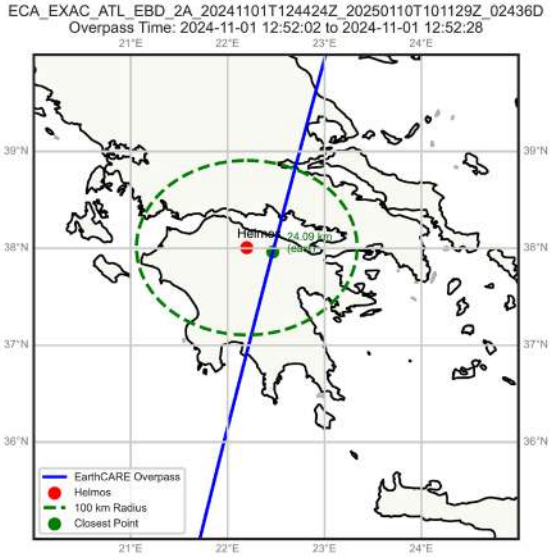

- EarthCARE overpass 23:23:29 – 23:23:44
- Nicosia lidar average 23:20 – 23:30 UTC **532 nm**
- PollyXT Limassol average 23:00 – 23:59 UTC **baseline AC**

- **Nicosia Lidar**: extinction coefficient @532 nm remains ~100 $Mm^{-1}$ up to ~2.8 km, then decline reaching near-zero at ~3 km, no other layer above this altitude, **PDR 532 nm: 20%**
- **PollyXt Limassol:** extinction coefficient @355 nm <100 $Mm^{-1}$ up to ~2.5 km, elevated aerosol layer ~3.3 km, **PDR: ~14%**
- **EarthCARE EBD**: extinction coefficient @355 nm between ~120 and ~160 $Mm^{-1}$ up to ~3.2 km, then decline reaching near-zero at ~3.4 km, **PDR: ~10%**
- **Higher VDR and PDR values** indicate a fraction of dust in the aerosol mixture, as classified by the ATC.
- **East-West gradient of aerosol layer top (sloping layer)**

# 20241101 EBD and ATC EarthCARE products

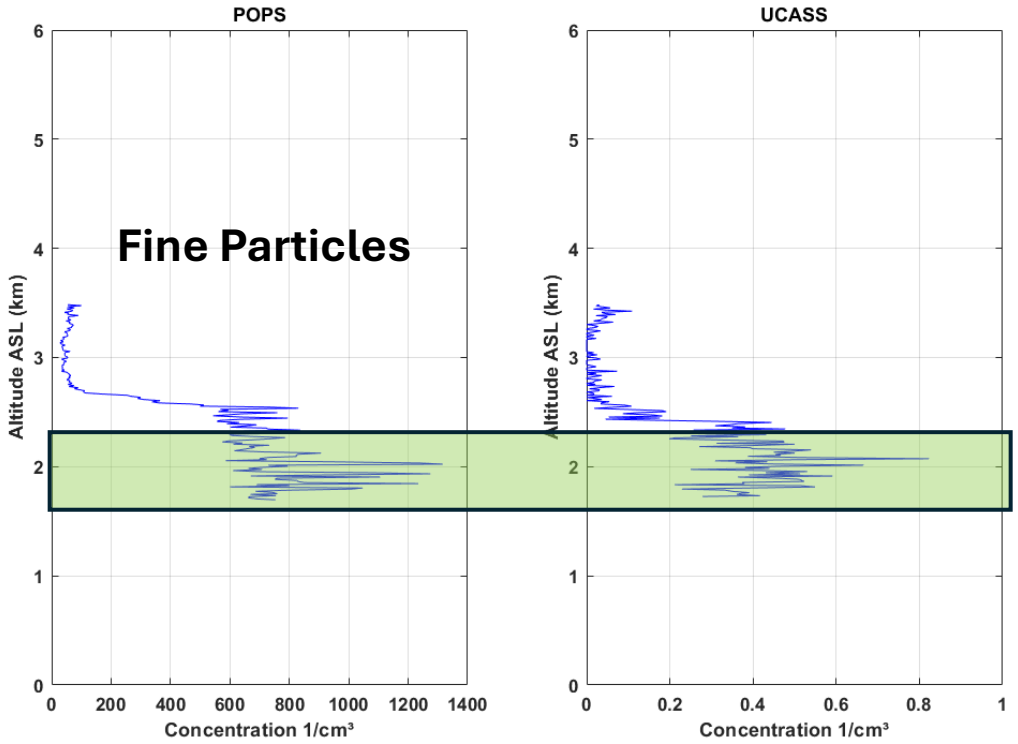


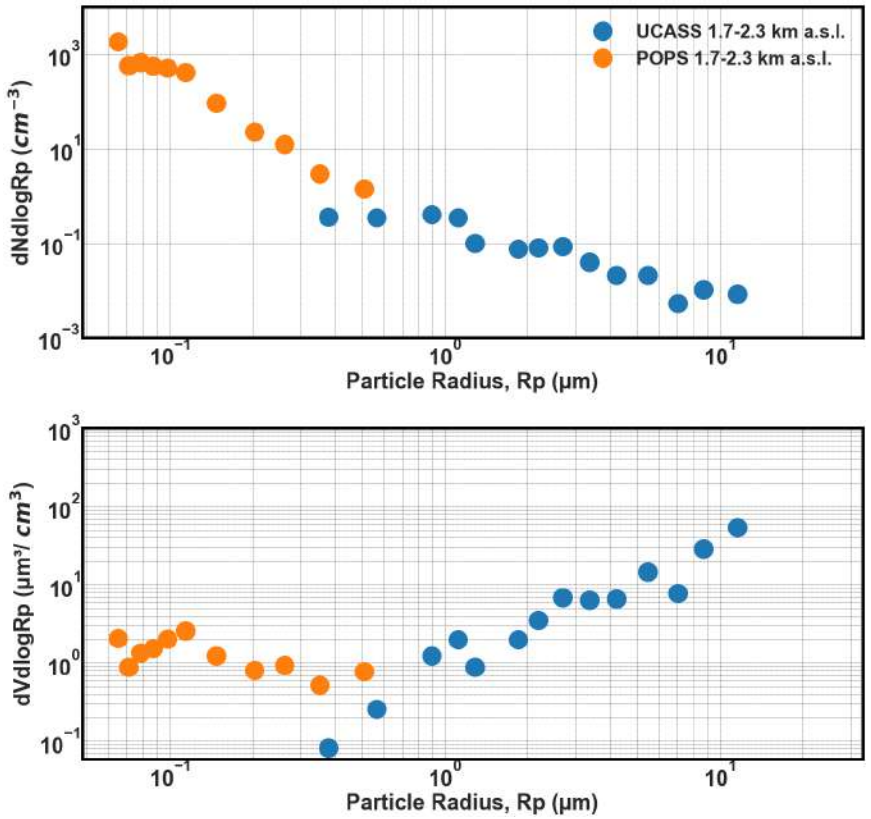




- **Closest overpass**: ~24 km east of Mt. Helmos
- **Dusty mix**: Major classified type by ATC, up to ~2.5 km.
- **Continental pollution**: Classified by ATC too.
- **Sea salt beneath clouds**: Possible artifact?

# 20241101 UAV observations




- POPS concentrations >1000 particles/cm³, UCASS significantly lower concentrations ~0.5 particles/cm³
- POPS: well-mixed aerosol layer confined below ~2.3 km
- UCASS: Coarse particles layer below ~2.3 km, indicative of dusty mix

# Conclusions and next steps

- First analysis suggests that **ATLID**, the **ground-based lidars** and the **UAVs** show a consistent picture of the observed aerosol layers and aerosol types over Cyprus
- **To be investigated: Spatial Variability in Aerosols**: Averaging all cloud-free profiles within 100 km may introduce biases, as different aerosol types (e.g., sea salt over the sea) contribute to the signal, potentially affecting direct comparisons.
- **ATC: Possible artifacts beneath clouds** or classified as sea salt aerosol layers above continental pollution layers.
- **Future data acquisition efforts: Identify Stronger Aerosol Events**: Focus on cases with stronger aerosol signals (e.g., dust events) to enhance the comparison and validate EarthCARE's ability to capture high-aerosol-loading conditions.

"Until February 2025, the CYI activity for EarthCARE cal/val has been in part supported by ATMO-ACCESS through the EarthCARE cal/val pilot, however this project has now come to an end. Moreover, activity at Mt. Helmos in October 2024 received support from the CleanCloud project. From March 2025 there is an uncertainty in the amount of resources that can be dedicated to this activity, due to the current funding status, but we will do our best."